2.—SOME KYANITE-BEARING ROCKS FROM THE EASTERN GOLDFIELDS, WESTERN AUSTRALIA.*

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INTRODUCTION.

While engaged in a programme of field work undertaken by the Geological Survey in the country north of Laverton, Mt. Margaret Goldfield, during the winter of 1939, the writer noted and mapped at a spot known as the Camel Humps, an interesting occurrence of a variety of rock hitherto unrecorded from this district. This is a kyanite-bearing quartz schist, a fairly high grade metamorphic type, and part of the Older Greenstone Series (Pre-Cambrian) which forms a narrow belt of auriferous country in this portion of the State.

Comparison of this rock with rather similar looking metamorphics from a number of other localities in the Eastern Goldfields has led to the discovery or confirmation by the writer, of the existence of kyanite in several of these latter rocks also, and the object of this paper is to give a brief description of the occurrence and petrology of these interesting rocks.

The presence of the mineral kyanite in crystalline schists is of peculiar interest, because of the light that it may shed upon the origin, constitution and metamorphic history of the rock in which it is developed. It is a silicate of aluminium, $Al_2O_3SiO_2$, and is generally recognised as one of the few typical "stress minerals" (1), and appears to form only at definite stages in progressive regional metamorphism. It is a mineral which is peculiarly sensitive to changes in temperature and pressure conditions, and requires

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for its development, appropriate conditions of moderately high temperature in conjunction with essential shearing stress. It appears to have only a temporary status or field of stability in regional metamorphism, and together with its polymorphs, andalusite and sillimanite, has been for a long time regarded as a "key" mineral, indicative of a certain distinct grade or zone of metamorphism. (4 p208 et seq.), (3), (2).

Kyanite has been recorded from comparatively few localities in Western Australia, these being mostly confined to the Chittering Valley, (5), (6), (7), and (11), and the Chittering-Jimperding-Clackline-York belt of metamorphic rocks generally (8). Specimens of kyanite have been obtained from other scattered localities i.e., from Richenda River, West Kimberley, (where it is associated with emery); Milly Milly Station, Murchison River (9); Smithfield and the Donnelly River, near Bridgetown in the South-West Division, where it occurs in patches of waterworn boulders (12), (10), and (13); Mt. Barren, South-West Division; but little if anything is known of the field relations of many of these occurrences. From the Goldfields, one occurrence of a mineral rather doubtfully referred to kyanite, has previously been recorded. (14). This is from the vicinity of Mt. Kenneth in the Yalgoo Goldfield, and this rock will be described in some detail below. It is proposed to discuss separately the occurrences and petrographical details of the several kyanite bearing rocks which have been noted.

Photo. K. R. Miles, 1939.

Fig. 1.—Hills of the northern Camel Humps, looking east. Soil and talus in the foreground.

THE CAMEL HUMPS, MT. MARGARET GOLDFIELD.

Field occurrence.

The Camel Humps is the name given to two prominent ridges standing up in marked relief above rather low, flat or gently undulating country lying some $2\frac{1}{2}$ miles west of the main Laverton-Cox's Find road, at a point about 33 miles north of Laverton. These two ridges lie a little over half a mile apart on a north-northwesterly line, their highest points being marked by small cairns. The northern Camel Hump is the more prominent and consists of a long ridge extending over a length of more than 20 chains, broken by

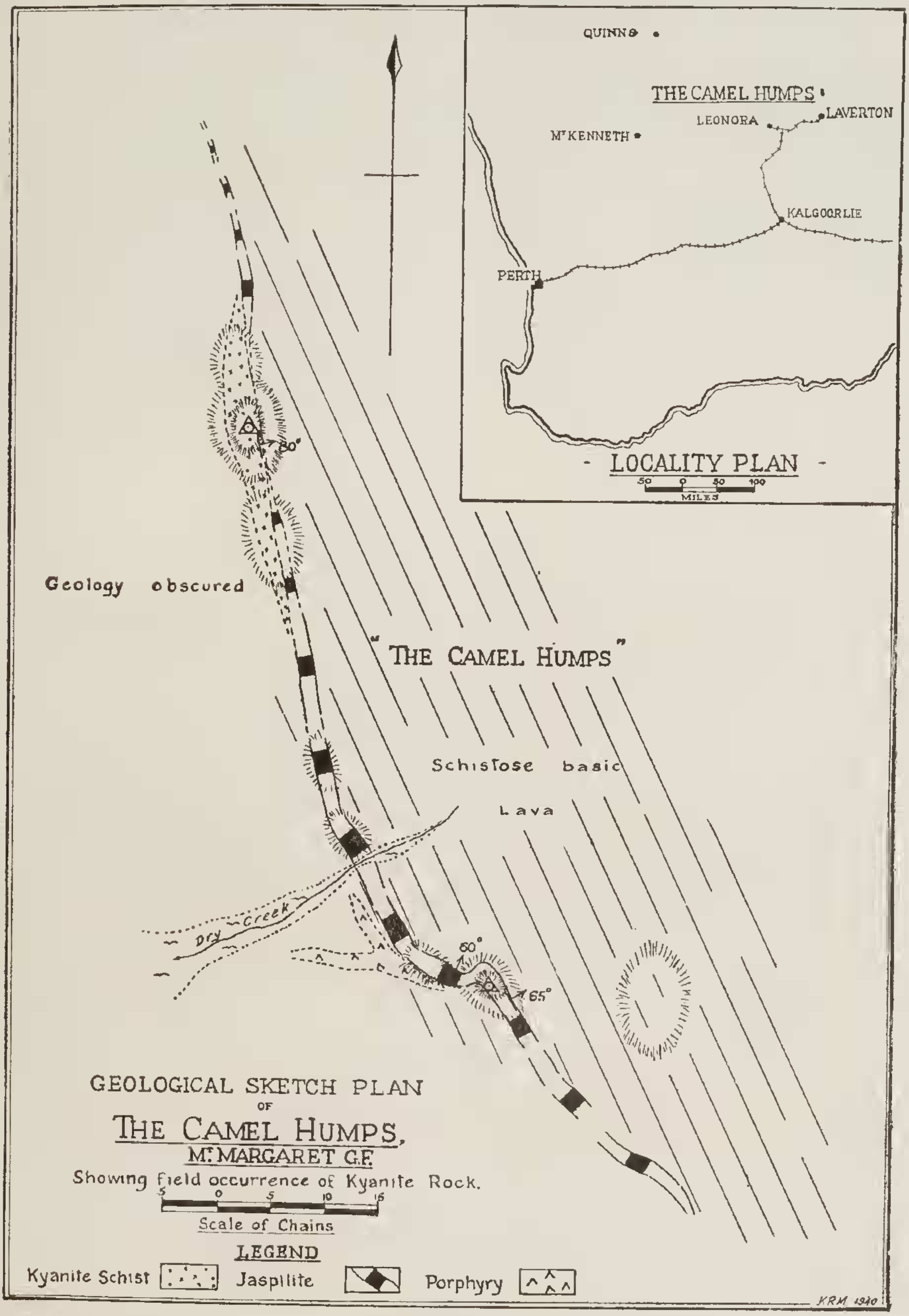

Fig. 2.

erosion gaps into three hills, the central and highest carrying a cairn. (Fig. 1.) These hills are made up of outcrops of a hard yellowish-white coloured, rudely jointed and bedded quartzose rock which dips from vertical to 80 degrees to the east. The jointing has resulted in the production of large slabs of rock which often stand up like enormous blunt spear heads. Both the western and eastern slopes of the ridge are steep to precipitous, and strewn with these flat slabs and with smaller rock talus, and sprinkled with sparse mulga scrub.

On the western side of the hills this talus, together with red gravelly soil and milk white quartz rubble, completely obscures the geology. To the east, though outcrops are scarce, the country appears to consist principally of decomposed greenstone schists, probably schistose basic lava. On traversing the ridge southwards one sees that the yellowish quartzose schist lenses out along the strike, and without any visible unconformity its place becomes taken by a banded ferruginous quartzite bed. This relationship is shown in the geological sketch plan. (Fig 2.). Outcrops of this banded ferruginous quartzite or jaspilite extend southwards in a series of low hills forming a curved line linking up with the hills of the southern Camel Hump. (See Fig. 2.). To the immediate north of the northern Camel Hump hills the country flattens out into a rubble-covered plain but traces of a banded ferruginous quartzite bed can be found extending for nearly a quarter of a mile to the northwards.

Petrography.

A close inspection of hand specimens (L397.)* of this yellowish-white rock taken from near the cairn at the northern Camel Hump discloses the presence of a knotted schistose structure. The knots consist of kyanite in either rounded rather stumpy crystals averaging about 2 mms. in diameter and 2.5 mms. long, or longer flat bladed crystals up to 6.5 mms. in length. Most of these crystals are roughly oriented so that their shorter axes lie approximately normal to the plane of schistosity. They are colourless and have a lustre ranging from dull vitreous to distinctly pearly upon cleavage faces. These knots of kyanite are set in a "flowing" or foliated aphanitic matrix of whitish, very finely granulated quartz, usually flecked with tiny flakes of sericite giving a silky sheen to surfaces of the rock which have been broken parallel to the schistosity. This quartzose matrix is here and there stained yellowish or pink by a little introduced limonite.

It has a porphyroblastic gneissic structure—the porphyroblasts of kyanite being arranged in rudely oriented bands of very irregular shaped crystals whose boundaries are frequently crenulated and embayed, whilst the terminations are generally resolved into a granular diablastic aggregate of kyanite and quartz.

Individual crystals of kyanite are occasionally curved and bent due to rotation during growth. In thin slice they are colourless and non-pleochroic and have characteristic high relief. Many elongated sections show a well defined cleavage (100) while sections cut parallel to this disclose an imperfect (010) cleavage. The cross parting (001) at approximately 85° to the length of the crystals, i.e., the c-axis, is seldom well developed (See Fig. 3A.). End sections (cut approximately normal to the c-axis) disclose the perfect (100) cleavage whilst the (010) is represented by a strong cross parting at from 80°-85° to (100) (See Fig. 3B.) In such sections extinction is parallel to (100) cleavage.

* All numbers in parentheses represent either field or registered numbers of specimens in the Geological Survey Rock Collection—except those preceded by the letter U. which belong to the General Collection of the Dept. of Geology, University of W.A.

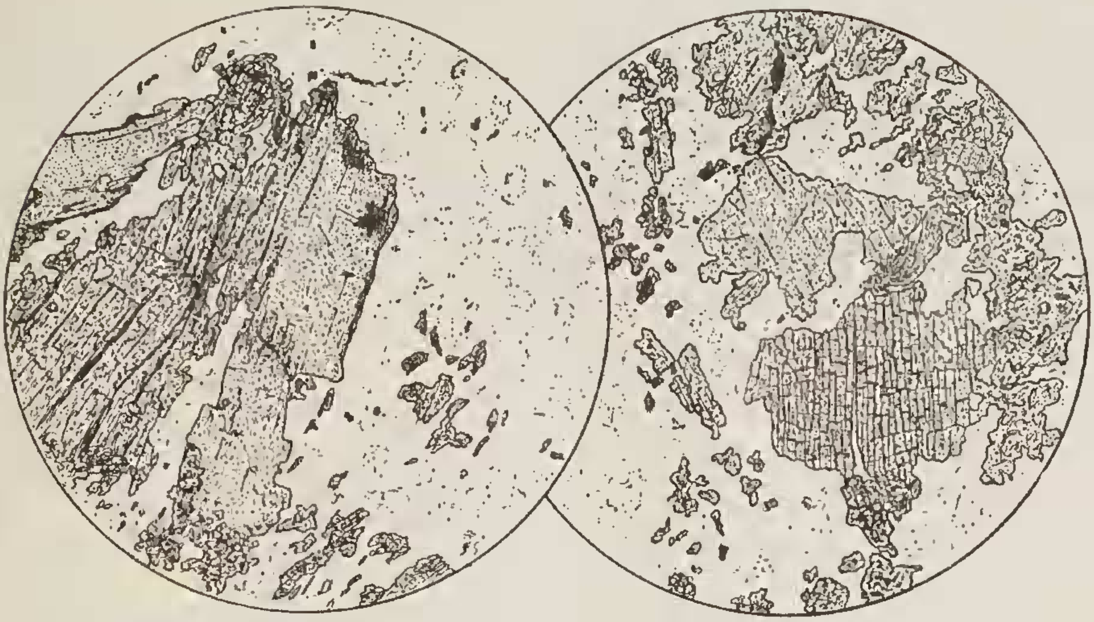

Fig. 3.

A. Kyanite-quartz schist (specimen L397) from the Camel Humps. Showing characteristic bladed form of kyanite cut parallel to (100) (clear crystal). Rutile inclusions in clustered aggregate (black).

B. The same, with kyanite crystal showing perfect (100) cleavage and imperfect (010) cross-parting in section cut approximately parallel to (001). Note diablastic intergrowth of granular kyanite with quartz matrix.

The following optical properties have been determined:—

The optical elongation is positive. $Z \wedge c$ is 29°-30° on sections cut parallel to (100).

The mineral is biaxial with negative optical character.

Optical axial plane is approximately normal to (100) and inclined at 29°-30° to c-axis.

2V is large ($\simeq$ 80°).

The refractive indices are:—

$$\left.\begin{array}{l}\alpha = 1{\cdot}711 \\ \beta = 1{\cdot}718 \\ \gamma = 1{\cdot}726\end{array}\right\} \pm \cdot 002$$

$$\gamma - \alpha = \cdot 015 \qquad \pm \cdot 002$$

Twinning, often a characteristic feature of this mineral, was only occasionally noticed on (100) as twin plane. Micrometric observations indicate the presence of 15% to 25% of kyanite in this rock. Inclusions in these kyanite porphyroblasts consist of quartz grains, clusters of yellow rutile prisms and occasonal detrital zircons.

The quartz matrix enclosing the kyanite consists of a fine grained, evengranular mosaic of crystals averaging about .04-.08 mms. in diameter, included in and surrounding the broken grains of kyanite.

Quartz and kyanite constitute the essential minerals in this rock.

Accessory minerals present are:—

Rutile in very abundant scattered clusters and separate individuals of tiny golden yellow prismatic crystals frequently occurring in geniculated twins, often as poikiloblastic inclusions in kyanite, but also scattered irregularly throughout the quartzite matrix.

Sericite or muscovite occurs in some tiny parallel oriented rods "flowing" throughout the quartzite matrix and also as a few larger flakes and stringers occasionally moulded upon or enclosed by kyanite.

Zircon exists in a few rounded, colourless, zoned detrital grains often enclosed in kyanite.

Hematite is present in a few small scattered grains, usually showing some alteration to limonite, while limonite occurs as a thin secondary stain in a few places, marking the presence of small fractures upon the surface of the rock.

Thus this rock is a kyanite-quartz schist.

The simple mineralogical composition of this rock indicates a comparatively simple chemical composition. From its mineral content it would appear to consist chiefly of silica, SiO_2, and alumina, Al_2O_3, with minor quantities of titanium oxide, TiO_2. A remarkable feature of this rock is the almost complete absence of Fe in any form, particularly as from the field occurrence it appears to grade into normal banded ferruginous quartzite along the strike.

No chemical analysis of this rock has yet been made but as will be seen in the following section its remarkably close similarity to the Mt. Leonora rock indicates an essentially similar chemical composition, and an analysis of the Camel Humps rock would probably be found to compare very closely with those of the Mt. Leonora type quoted below.

MT. LEONORA, MT. MARGARET GOLDFIELD.

Field occurrence.

Mt. Leonora lies about 3 miles to the south-southeast of the townsite of Leonora and forms the highest and most conspicuous summit of a long line of intermittent ridges and low hills which run northwards for many miles. These also extend southwards from the Trig. Station for about three miles in a line of rock outcrops which form ridges of gradually decreasing stature and which finally disappear beneath the alluvial flats of Lake Raeside. The rocks of which Mt. Leonora is composed are creamy yellow to light grey in colour and are usually dense, hard quartzose schists of variable grain size, frequently having a knotted character.

These rocks are distinctly bedded and dip fairly constantly at 55° to the west (See Fig. 4.). They were first described in 1904 by C. F. V. Jackson (15) who considered Mt. Leonora to be an area of "crushed granite," despite the evidence of a chemical analysis of this rock (5084) published along with his description.

In 1909 A. G. Maitland, as a result of a brief re-investigation of the field occurrence of the Mt. Leonora rock, pointed out its obviously bedded nature and from the field evidence concluded it to be of sedimentary origin and not a metamorphosed granite (16). He also remarked that the quartz schists of the Mt. Leonora type extended northwards for over six miles without interruption to Mt. George.

In the geological map accompanying his report on the geology of Leonora, Jackson (op. cit.) shows a broken line of ridges running southward from Mt. Leonora, apparently forming the southern continuation of the strike of the Mt. Leonora rock, for over two miles. Similar ridges are also shown running northwards from the eastern outskirts of Leonora township to beyond Mt. George. The centre of all this line of ridges is mapped as composed of a more or less continuous bed of "banded hematite-bearing quartz."

G.S.W.A. Neg. No. 196. *Photo. C. F. V. Jackson.*

Fig. 4.—Outcrops of andalusite quartz schist, or quartzite, Mt. Leonora, showing bedding planes dipping at about 55° to the west.

Outcrops of this rock on the eastern edge of the townsite are certainly those of quite typical bedded ferruginous quartzite or jaspilite, and consequently it would appear that in its broad geological association with these jaspilite beds the Mt. Leonora rock shows a striking similarity to the Camel Humps occurrence, described above.

In his bulletin dealing with the field geology of the Leonora-Duketon District, E. de C. Clarke (17), in an account of the Mt. Leonora rock quoted Farquharson's determination of it as a "finely foliated, much granulated andalusite-quartz schist which he considers to be a metamorphosed sediment." Chemical analyses of specimens collected by Jackson (5084) and by Clarke (1/2002) were compared with two analyses of metamorphic rocks from Quinn's, (Murchison Goldfield), and their general similarity noted. These analyses are quoted below.

Petrography.

A recent re-examination by the writer, of a number of the old thin slices together with several new ones cut from different specimens of the Mt. Leonora rock has disclosed the interesting fact that, in addition to andalusite, some hand specimens also contained the higher grade metamorphic minerals, kyanite and sillimanite. In fact different specimens of this rock provide excellent examples of arrested mineral development with the inception of a higher grade facies due to change in stability conditions during progressive metamorphism.

Hand specimens of this rock collected from various points in the vicinity of the Trig. Station and from the western slopes, are creamy white to grey in colour and of varying density and grain size. Coarser grained specimens are much more foliated or schistose and have a strong knotted structure and a characteristic silky lustre on cleavage planes. The knots, presumably representing andalusite crystals, are usually rounded and flattened and show up as slightly lighter colour than the foliated matrix. They may be up to 7.5 mms. long and nearly 5 mms. wide. The finer grained specimens are much more compact and though not markedly schistose, have a tendency to cleave along parallel planes. The andalusite knots are only revealed on polished surfaces and then appear as innumerable small roundish, light coloured patches, averaging less than 1 mm. in diameter. The material surrounding these knots appears dense, fine grained and siliceous.

In one hand specimen (5084), a medium-coarse grained schistose type, one can distinguish, in addition to the andalusite knots, a few small flat, pearly lustred laths of kyanite up to 2 mms. long.

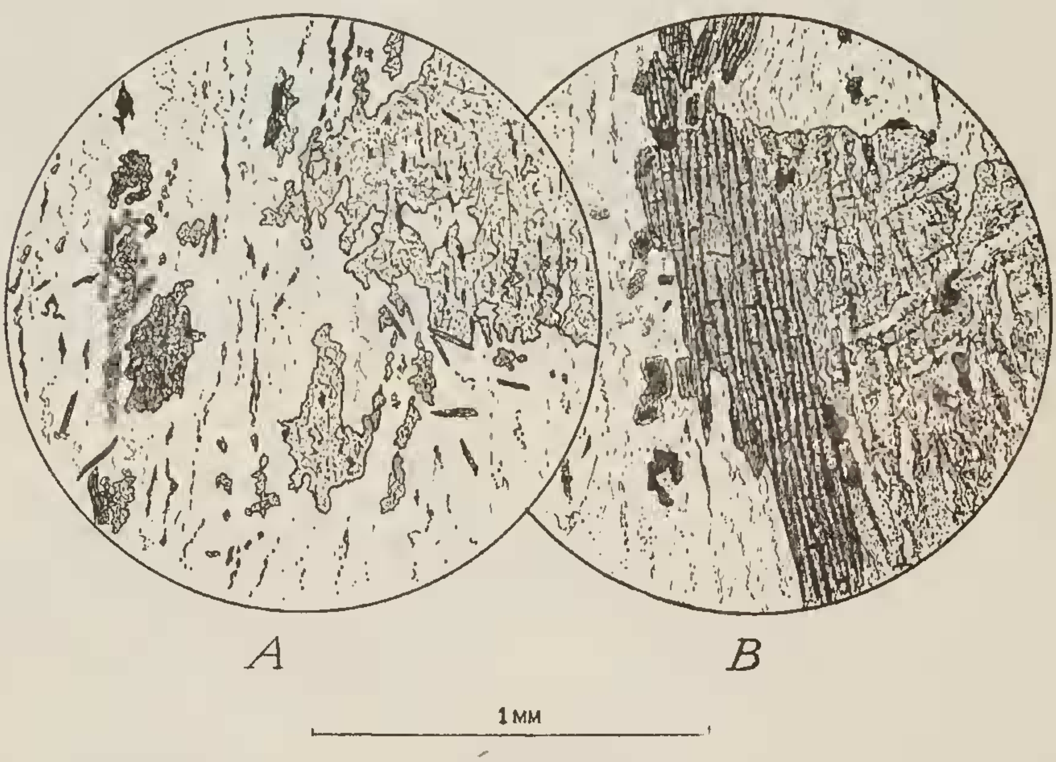

Fig. 5.

A. Kyanite-bearing andalusite-quartz schist (Spec. 5082) from near Trig. Station, Mt. Leonora. Showing part of a large granular porphyroblast and some granulated kyanite (darker). The quartzite matrix contains flakes of muscovite and oriented stringers of dark carbonaceous material.

B. Sillimanite-bearing andalusite-quartz schist (Spec. U3165) from near west slope of Mt. Leonora. Showing sillimanite in flowing needles developing upon the margin of granular poikiloblastic andalusite. Black opaque grains are hematite altering to limonite, and some graphite.

Thin slices show a uniform porphyroblastic gneissic texture. The "knots" or porphyroblasts consist chiefly of colourless andalusite. This mineral has reached only a very early stage of crystalloblastic development, the "knots" being more or less equidimensional but otherwise without form. Indeed so weak has been the force of crystallisation of the andalusite that crystals have in most cases entirely failed to clear themselves of inclusions, which consist of flowing aggregates of quartz granules, finely divided dusty graphitic material, shreds of mica, and scattered yellow rutile needles, identical and continuous with the material of the matrix which surrounds these porphyroblasts. Only seldom has the andalusite developed clear crystals showing any semblance of form, but where seen these usually show characteristic prismatic (110) cleavage and have moderately low relief, weak birefringence, straight extinction in elongated sections, negative elongation and negative optical character. A few sections occasionally show a faint pleochroism from Z = pale pink, to X and Y = colourless.

Kyanite is present as porphyroblasts in a few specimens (e.g. 5084, 5082, U17265) and usually forms rather irregular shaped elongated crystals or occurs in granular aggregates indicating an early stage of growth. The kyanite is sometimes partially enclosed in granular aggregates of andalusite from which it is developing, or it may occur as isolated porphyroblasts in the quartzite matrix. (See Fig. 5A.) It is easily distinguished from the andalusite by its high relief and consequent darker appearance, and by its typical bladed form, cleavage, extinction angle, stronger birefringence and positive elongation. Twinning on (100) was noticed in several crystals. Though characteristically showing a much stronger force of crystallisation than the andalusite, crystals are never entirely free of inclusions of quartz granules, carbonaceous material and some rutile needles, while the terminations of the crystal blades are usually broken into granular aggregates and occasionally resolved into needle-crystals of sillimanite.

Sillimanite is present in several specimens (U3165, 10833) usually associated with and developing directly from granular andalusite (See Fig. 5B). It occurs in slender elongated and cross-fractured prismatic crystals or in felted masses of acicular fibres, generally lying in parallel optical orientation with the andalusite. These are distinguished from the andalusite by their form, higher relief, stronger birefringence and positive elongation, and where associated with granular kyanite, from this mineral by their straight extinction.

The matrix enclosing the porphyroblasts consists mainly of a finegranular lepidoblastic aggregate of quartz, charged with some finely divided carbonaceous material, together with scattered oriented shreds and flakes of sericite, and frequently abundant tiny yellow granules and prisms of rutile.

Accessory minerals include small quantities of iron-ore—both hematite and limonite, and also occasional limonite pseudomorphs after pyrite, fragments of brown mica, and a few zircons, all distributed sporadically throughout both the matrix and the porphyroblasts.

Thus the Mt. Leonora rock may be said to vary in mineralogical composition from andalusite-quartz schist or quartzite, to kyanite, and sillimanite-bearing andalusite-quartz schist. Their similarity of chemical composition is clearly demonstrated, however, in the analyses quoted below. (A) and (B). Their essential similarity to the Camel Humps rock is also very noticeable, the chief mineralogical differences arising from differences in temperature and pressure conditions during metamorphism, as will be discussed in a later section.

MT. KENNETH, YALGOO GOLDFIELD.

Field occurrence.

Another interesting metamorphic which bears a general resemblance to the Camel Humps and Mt. Leonora rocks, comes from several low rocky rises at about seven miles east-southeast of Mt. Kenneth, near the eastern boundary of the Yalgoo Goldfield. This occurrence was described by H. W. B. Talbot in 1919 (14) and a chemical analysis, and brief petrographical description by R. A. Farquharson, were also published. The field relations of this rock are rather obscure, but it is apparently enclosed and presumably intruded by granite.

Petrography.

The rock is pale greenish in colour, is medium grained and has a typical even, granulated schistose appearance, but has not the marked knotted, or porphyroblastic structure of the two rocks described above, and hand specimens appear to consist chiefly of quartz and chlorite.

The microscope, however, reveals the presence of numerous ragged prisms and irregular, rather fragmentary crystals of typical kyanite showing usual high relief, good (100) cleavage, moderate birefringence and positive elongation, with characteristic maximum extinction and negative acute bisectrix figure obtained from broad sections cut parallel to (100). These crystals are occasionally enclosed by and apparently developing from chlorite and sericite flakes, or are scattered in groups in random orientation through an irregular cataclastic granular matrix of quartz, and irregular ragged plates of chlorite and muscovite.

The most common accessory mineral in this rock occurs in small irregular, rather pointed prisms and rounded granules, scattered liberally throughout. These are pleochroic in dark yellow-brown to red-brown colours, maximum absorption being parallel to the longest axis. Relief is very high, surfaces of these crystals having a stippled appearance. Birefringence appears weak, and interference colours are mostly masked by absorption. Extinction is straight. A few grains show apparent development of penetration twins. Grains were too small to give an interference figure. They have the colour, general form and extremely high refringence of perovskite, ($CaTiO_3$) whilst the pleochroism and extinction suggest either brookite, (TiO_2), or the metamorphic mineral staurolite (hydrated silicate of Fe and Al.). The entire absence of CaO in the chemical analysis of this rock (C) rather disposes of the possibility of perovskite. The general distribution is that of a detrital mineral and brookite is suggested.

Other accessories include clear yellow-brown rutile in euhedral prisms, pale yellow zircons often producing pleochroic haloes in chlorite, broken apatite needles, and a few grains of cloudy felspar.

In 1920 E. de C. Clarke visited the Mt. Kenneth district and collected a suite of specimens of the metamorphic rocks. Several of these hand specimens (1/2694, 1/2695) resemble very closely Talbot's specimen described above. Examination of thin sections failed to reveal the presence of any kyanite however, the indications being that these rocks have apparently failed to pass the chlorite stage of metamorphic development (4, p 209). They consist essentially of quartz, muscovite stained with limonite, and some pale green chlorite. Of the accessories, rutile in bright yellow recrystallised prisms and dark detrital grains is most abundant. Others include detrital zircon and apatite.

Chemical analyses of Talbot's rock and of one of these (1/2695), given below, clearly indicate their common composition, however, and strongly suggest their common origin.

QUINN'S, MURCHISON GOLDFIELD.

Field occurrence.

From a little over half a mile to the south-west of Quinn's townsite in the Murchison Goldfield, comes another set of metamorphic schists, comparable with those described above. These rocks were first described in 1904 by C. G. Gibson (18) who believed them to be granite schists. In 1921 they were further described and figured by F. R. Feldtmann (19) and a brief account was given of their field occurrence. Petrographic descriptions of a number of these rocks were provided by R. A. Farquharson (19, p16) who considered several of them (1/791-2) (1/794) (5332-3) to be metamorphic chloritic quartz schists containing a granular mineral which he doubtfully referred to andalusite. Feldtmann concluded that they were contact metamorphosed sediments. Analyses of two of the rocks (1/791 and 1/792) which are quoted below, were also published.

Petrography.

Hand specimens of one of these metamorphics (1/791) are pale greenish grey coloured, rather uneven, medium to fine grained, granulated with an unusual streaky appearance, consisting mainly of pink and colourless quartz, and abundant pale green chlorite scales.

This rock has a granulated porphyroclastic texture, with scattered "eyes" of slightly broken, clear quartz in a fine granulated matrix of rounded quartz grains and chlorite shreds. The granular mineral referred to andalusite by Farquharson occurs in several roughly rectangular patches, enclosing abundant grains of quartz and chlorite and some rutile needles. The determinable optical characters of this mineral are those of andalusite present in a very early stage of skeleton growth.

In addition to the andalusite, the specimen also contains kyanite in a few small ragged elongated prisms, usually enclosed by and apparently developing at the expense of chlorite, but also occasionally associated with the andalusite. These crystals have moderately high relief, moderate birefringence, positive elongation, maximum extinction angle on (100) of about 30° ($Z \wedge c$), negative optical character and large axial angle, and undoubtedly represent an incipient growth of kyanite.

Other minerals include scales of muscovite associated with abundant altered chlorite, a few cloudy grains of kaolinised felspar, rutile in pale yellow prisms, a few clusters of dark yellow irregular shaped granules with extremely high relief (probably brookite), zircon, apatite and a little granular carbonate.

A second rock (1/792) from the same area has a similar texture in hand specimens but is of a mottled pink colour. Small clear white crystals of andalusite can be seen scattered through a fine granular matrix of pink quartz and pale green to colourless mica flakes.

The thin slice reveals a typical porphyroblastic granular texture of andalusite in quite well crystallised products crowded with fluid inclusions, grains of quartz and a few rutile needles, and usually surrounded by and apparently altering to aggregates of scaly colourless chlorite, with some muscovite, set in a ground mass of clear broken and irregular to rounded quartz grains, and interstitial fibrous chlorite, and sericite.

Kyanite occurs in one or two scattered crystals distinguished from the andalusite by their characteristic bladed form and higher relief. Other accessories include rutile, in tiny rods and geniculate twins ranging from almost colourless to dark yellow and occurring often in clusters or in strings of crystals, and fragments of bleached, obviously detrital biotite, and a few grains of zircon.

ORIGIN AND METAMORPHISM.

Following are the chemical analyses of the Mt. Leonora, Mt. Kenneth and the Quinn's rocks:—

	A.	B.	C.	D.	E.	F.
SiO_2	76·71	82·74	72·57	75·35	78·28	84·11
Al_2O_3	20·08	14·84	10·15	11·35	9·48	8·05
Fe_2O_3	1·70	·43	·49	·79	·40	*Nil*
FeO	...	...	2·70	1·76	2·65	·62
MnO	*Nil*	*Nil*	·05	·12	·03	*Nil*
MgO	·06	*Nil*	9·38	4·69	5·60	4·21
CaO	·56	·09	*Nil*	Trace	·11	·18
Na_2O	·07	·40	·34	·30	·23	·25
K_2O	·11	·26	·28	2·06	·19	·18
H_2O —	·21	·03	·02	·10	·06	·06
H_2O +	·24	·17	3·19	3·10	3·19	2·15
TiO_2	·66	1·33	·57	·51	·04	·05
P_2O_5	...	Trace	·20	·07	·05	·01
ZrO_2	...	...	...	Present	Trace	Trace
CO_2	...	...	...	·03	·02	*Nil*
FeS_2	...	...	...	·17	*Nil*	·02
	100·40	100·29	99·94	100·40	100·33	99·89
Sp. Gr.	2·81	?	?	2·72	2·70	2·67
Analyst:	C. C. Williams.	H. Bowley.	H. Bowley.	D. G. Murray.	H. Bowley.	H. Bowley.

A. Spec. 5084 Kyanite-bearing andalusite-quartz schist. Vicinity of Trig. Station, Mt. Leonora, Mt. Margaret Goldfield (15, p19).

B. Spec. 1/2002 Andalusite-quartz schist. West slope of Mt. Leonora, Mt. Margaret Goldfield (17, p25).

C. Spec. 1/1679 Kyanite-bearing quartz-chlorite schist. 7 miles east-south-east of Mt. Kenneth, Yalgoo Goldfield (14).

D. Spec. 1/2695 Quartz-muscovite schist. Near Camel Paddock (162M. on No. 1 Rabbit Proof Fence) vicinity of Mt. Kenneth, Yalgoo Goldfield.

E. Spec. 1/791 Andalusite bearing quartz-chlorite schist with incipient kyanite. Dump of No. 2 Stock Well, near Water Res. 13435, Quinn's, Murchison Goldfield (19, p18).

F. Spec. 1/792 Andalusite-quartz-chlorite schist with incipient kyanite. Princess Dagmar Water Shaft, GML 843N, Quinn's, Murchison Goldfield (19, p18).

An examination of the above analyses clearly indicates the essential similarity of the rocks, and the variations closely reflect the mineralogical differences. In general they all show a very high percentage of SiO_2, and a notable excess of Al_2O_3 over the 1 : 1 ratio necessary to satisfy the CaO and the alkalies present. From the alumina content the percentage of andalusite, kyanite, etc., present in the Leonora rock is 30.8% for A and 20.80%

for B, and in the Quinn's rocks 5.36% for E and approximately 5.00% for F. In the Mt. Kenneth rocks this figure lies between 10% and 11% for C, while for rock D the amount of alumina available after satisfying the soda and potash is too small to permit of the production of any andalusite. The percentage of alkalies in most of the rocks is very low—in all but one specimen (D) being less than 0.7% and of these the Na_2O content is generally slightly in excess of the K_2O. The Mt. Kenneth and Quinn's rocks all show an overwhelming dominance of MgO over CaO— and the total lime content in all the rocks except A is extremely low.

The high silica percentage, the predominance of alumina over lime and the alkalies, the dominance of magnesia over lime and the low alkali content are criteria favouring the sedimentary origin of a metamorphic rock. (20). The presence of large quantities of andalusite or the allied kyanite or sillimanite in quartzose crystalline schists reflects the existence of an abundant alumina content and is usually a reliable indication of contact or thermal metamorphism of original sedimentary material in the case of andalusite, and of a higher grade more regional type of metamorphism where kyanite or sillimanite predominates.

The Camel Humps and Mt. Leonora Rocks.

As has already been shown by the microscopic descriptions, the Camel Humps and Mt. Leonora rocks are similar in composition, the essential minerals of the former being quartz and kyanite with minor quantities of rutile, and of the latter quartz, andalusite (and kyanite or sillimanite) and rutile. The accessories in each case are confined to a little mica, iron ore and detrital zircon, with possibly a slightly increased quantity of graphitic material in the Leonora rock. The percentage of aluminium silicate minerals in both is approximately the same, ranging from about 20% to 30%.

The microscopic texture and the mineralogical and chemical compositions of both the Camel Humps and the Leonora rocks, then, are essentially typical of metamorphosed sedimentary rather than igneous rocks. They were probably both originally fairly pure, fine grained argillaceous sandstones (slightly carbonaceous in the case of the latter) derived from the mechanical denudation of an original granitic or acid sedimentary terrain. Without considerably more detailed field observations little can be said regarding the conditions of sedimentation but the material originally deposited evidently consisted of an admixture of fine sand and clay, which suggests a comparatively rapid deposition with little mechanical sorting under such conditions as may be expected to exist, say, in deep water near the mouth of a stream channel. The apparently localised occurrences of the clay-bearing sands within what appear to be extensive ferruginous sandy beds may also suggest original delta deposits.

The pronounced titanium content indicated by the abundance of rutile in both the Camel Humps and the Leonora rocks, and reflected in the analyses of the latter, was probably derived in part from detrital rutile but also from the break-down of the original leucoxene and biotite in the sediments before and during deposition. Under increasing temperature conditions fresh rutile has crystallised out contemporaneously with the development of the aluminium silicate minerals.

The metamorphism in both the Camel Humps and the Leonora areas appears to be essentially of the regional type due probably to depression of these portions of the earth's crust into a zone of higher temperature and pressure. It is conceivable that in the Camel Humps area these conditions were produced as a large scale granite contact-intrusion effect but it appears improbable that during such an intrusion shearing stress would remain sufficiently constant for the formation of kyanite as the sole representative of the aluminium silicate minerals. There is no evidence of the existence of andalusite at any stage in the development of the Camel Humps rock. In the field the nearest undoubted outcrops of intrusive granite are about a mile to the west of the outcrops of kyanite quartz schist. The actual contact is marked by a thick layer of overburden which covers the intervening country. The only other intrusive rock in the vicinity is a very small dyke of acid porphyry occurring near the southern Camel Hump. Contact thermal effects of this intrusion can be assumed negligible.

No large body of undoubted intrusive granite or other igneous rock is known to exist in the immediate vicinity of Mt. Leonora. The general north-south schistosity of the country in the neighbourhood of both the Camel Humps and Leonora was probably the result of regional shearing pressures mostly contemporaneous with the formation of the metamorphic minerals.

It is evident that the Mt. Leonora rock commenced recrystallisation largely under deficient shearing stress as shown by the predominant early development of the andalusite. At a slightly later stage, however, whilst the rock was still at a fairly high temperature, it became subjected to increasing shearing stresses—probably associated with folding movements responsible for the schistosity of adjacent greenstone. This pressure finally reached such a stage that further growth of the so called "anti-stress" mineral andalusite was completely inhibited and it commenced recrystallisation into the more stable kyanite and sillimanite.

According to Harker (4, p. 232-3) this association of andalusite with kyanite is decidedly rare. He quotes an occurrence in the Flüela district, near Davos (Switzerland), but here it is believed that the formation of the andalusite belonged to a later phase of metamorphism after a rapid falling off of shearing stress while temperatures still remained high. Examples of the growth of kyanite in pseudomorphs after chiastolite as a result of regional metamorphism superimposed on normal thermal metamorphism of an area of original pelitic sediments are recorded by C. E. Tilley from Ross-shire, Scotland (1).

The presence of such a high grade metamorphic mineral as kyanite in rocks believed to form part of the Older Greenstone Series is of particular interest in so far as it shows that in some portions of the Mt. Margaret Goldfield this Series has suffered a higher grade of metamorphism than had previously been recognised there. In these localities the rocks have evidently been subjected to regional pressures and temperatures comparable with those which must have existed in some of the more advanced metamorphic areas of the State, e.g., the Chittering Valley and the Clackline-York districts. Igneous greenstones, believed to have been chiefly lavas contemporaneous with the sediments, probably form the bulk of the Older Greenstone Series in most parts of the Mt. Margaret Goldfield. In some places well preserved structural features indicate that these igneous greenstones have suffered very little metamorphism of any kind but in the localities described above the presence of kyanite in associated meta-sedimentary beds show that here at least they have been subjected to high stresses and temperatures. However, their composition is such that they show no striking evidence of these high grade metamorphic conditions which have produced in them some internal recrystallisation often with development of schistosity, but without any marked mineralogical reconstitution.

Finally the significant association of both the Camel Humps and the Mt. Leonora rocks with horizons of banded ferruginous quartzite should be once more noted. They may represent merely more argillaceous and non-ferruginous zones in such banded quartzites, or possibly portions of beds in which the iron content was largely leached away before metamorphism.

It is interesting to note that such minerals as andalusite and sillimanite have been recorded as contact alteration products of banded ironstones near Bulawayo and Salisbury in Southern Rhodesia. (21).

Mt. Kenneth and Quinn's Rocks.

The Mt. Kenneth and Quinn's metamorphics bear a striking similarity to each other in their chemical composition. The principal mineral differences are in the aluminium silicates, the Quinn's rocks containing predominant andalusite, whilst of the Mt. Kenneth types, one specimen (C) carried abundant kyanite while the other (D) has suffered but weak dynamic metamorphism with recrystallisation of white mica under inappreciable temperatures, and no alumino-silicate has been formed. These rocks differ from the Mt. Leonora and Camel Humps types mainly in their lower alumina content and greater proportions of ferrous iron, magnesia, and combined water. These differences are reflected in the much lower percentage of the aluminium silicate minerals and the relative abundance of such minerals as chlorite, muscovite, and to a lesser extent, biotite. A noticeable feature of all these rocks is their remarkably low lime content.

The Mt. Kenneth and Quinn's rocks both have the general appearance, texture and mineral composition, of original medium-fine grained, impure argillaceous grits, which since compaction have suffered some crushing under shearing pressures, and with increasing temperatures have reached an early stage of recrystallisation. In the case of one of the Mt. Kenneth rocks kyanite has been produced as a result of a continuation of shearing stress at the increased temperature. This stress must have been largely absent during the growth of andalusite in the Quinn's rocks but some retrogressive alteration of this mineral to chlorite and muscovite in specimen F suggests a later increased pressure during cooling.

SUMMARY.

During the 1939 field season of the Geological Survey, an occurrence of kyanite-bearing quartz schist, a type hitherto unrecorded from the district, was noted amongst the hills of the Camel Humps, north of Laverton, Mt. Margaret Goldfield. This rock is a fairly high-grade regionally metamorphosed sediment which forms portion of an horizon of banded ferruginous quartzite. In both its field occurrence and its petrography, it is closely comparable with an occurrence of metamorphosed sediments at Mt. Leonora, Mt. Margaret Goldfield.

Mt. Leonora rock is predominantly an andalusite-bearing quartzite or quartz schist in which the andalusite has reached only an early stage of crystalloblastic development. Although some specimens contain minor quantities of the higher grade stress minerals kyanite and sillimanite, mineral composion

indicates that, unlike the Camel Hump's type, shearing stress was largely ineffective during recrystallisation and when at all appreciable occurred only in the closing stages. The mineralogical compositions point to closely similar chemical compositions for the Camel Humps and Mt. Leonora rocks.

Two other interesting varieties of meta-sediments from Mt. Kenneth in the Yalgoo Goldfield, and from Quinn's in the Murchison Goldfield are kyanite-bearing quartz-chlorite schists and andalusite-bearing quartz-chlorite schists respectively, the latter containing incipient kyanite. Comparisons of the chemical analyses of these with the Mt. Leonora rock indicate that the two former consisted originally of very similar sedimentary material—argillaceous sands or fine grits—and that while this may have differed in minor details from the original Mt. Leonora (and Camel Humps) sediments, all these rocks were of essentially similar chemical composition. The existing mineralogical differences have been produced partly by slight chemical variations in the original sediments, and partly as the result of differences in the type and degree of metamorphism which they have suffered.

The discovery of a kyanite rock associated with the Older Greenstone Series in the Mt. Margaret Goldfield is of considerable interest in that it provides evidence of the existence in this district of an hitherto unsuspected high grade of regional metamorphism comparable with that found in such places as the Chittering Valley and the Yilgarn Goldfield.

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